STUDIES ON THE SO-CALLED PORPHYRITIC GNEISS OF NEW HAMPSHIRE.

CONTENTS.

Introduction.—The following paper embodies the results of some weeks of field work on the New Hampshire terrane, heretofore considered by some writers to be a metamorphosed Archæan sediment, but suspected by others to be eruptive. The conclusions of the author corroborate this suspicion and he has attempted to express them here with the special point in mind. The author desires to express his best thanks to Professor J. E. Wolff, of Harvard University, for valued suggestions and very material aid during the progress of the work.

Historical summary of opinion on the "porphyritic gneiss."—From the conspicuous nature of its outcrops the "porphyritic gneiss" of New Hampshire early attracted the attention of geologists. In the first annual report of the Jackson survey, in 1841, Whitney and Williams, in describing its occurrence remark that "large bowlders of porphyritic granite are very numerous over the sur-

face, from the west parish of Concord to the center of Warner, where we find the rock itself in place. It is a peculiar rock, having large crystals of feldspar uniformly distributed through its mass; they are often glassy, so as to furnish beautiful and striking specimens. This bed of granite extends across the state in a general northeast and southwest direction. It is from eight to ten miles in width, though often interrupted with veins of granite of various texture."[1] With the physical difficulties of a rugged, forest-clad country, it was not to be expected that accurate determinations of boundaries could be made by these geological pioneers. To this fact is due the confusion of the "porphyritic gneiss" and associated schists in the published Portsmouth-Claremont section of the Final Report.

In their section, "from Haverhill to the White Mountains," Whitney and Williams again refer to the formation thus: "From Meredith to Centre Harbor the rock in place is porphyritic granite, often traversed by beds and veins of fine grained, dark colored granite and trap. Some specimens of the porphyritic granite, in which the crystals of feldspar are flesh colored, are very beautiful. . . . . "From Centre Harbor to Plymouth the rock in place is porphyritic granite, traversed by occasional beds of mica slate."[2]

The first distinct mention of the "porphyritic gneiss" in the second (and last) survey of the state, that under the control of Professor C. H. Hitchcock, occurs in the second annual report, 1870. The preliminary map issued with that report roughly outlines the formation which he calls porphyritic granite. He describes it as "common granite full of large crystals of feldspar, generally from one-half of one to two inches long, which gives a checked appearance to the ledges. Some portions of it have evidently been injected, while the arrangement of the feldspathic crystals in parallel lines leads to the suspicion of stratification in other cases. When accurately mapped the area will resemble the trunk and branches of a decayed tree, the

[1] Final Report on the Geol. of N. H., C. T. JACKSON, 1844, p. 51.

[2] Op. cit. pp. 73 and 137.

branches corresponding to the veins which have been injected from the original mass.[1]

In the report for the next year, Professor Hitchcock adopted the view which was held throughout the later publications of the survey. On the map, of a scale of five miles to one inch, he differentiates the Lake Winnipiseogee and White Mountain areas, and gives a brief description of the rock, to which he affixes the name "porphyritic gneiss." He says: "This is an ordinary gneiss, carrying numerous crystals of orthoclase or potash-feldspar, from a quarter of one to two inches long. The longer axes may be parallel to the strike or arranged helter-skelter. It passes into granite with the same porphyritic peculiarity of structure. . . . . We suppose this to be the oldest formation among the mountains. Geologists speak of a rock of this character as common in the Laurentian in various parts of North America and Europe."[2]

At the twenty-first meeting of the American Association for the Advancement of Science, held in 1872, Professor Hitchcock expressly referred the "prophyritic gneiss" to the Laurentian[3] and noted the common parallel structure of the rock which he concluded to be the trace of an almost obliterated stratification.[4]

An indication of doubt as to an exact correlation appears in Professor Hitchcock's "Classification of the Rocks of New Hampshire," published in 1873.[5] He divides the various forma-

[1] Second Ann. Rep. upon the Geol. and Mineralogy of N. H., 1870, p. 33.

[2] Geology of New Hampshire, 1874, Vol. I, p. 33.

[3] Explanation of a New Geological Map of New Hampshire. Proc. A. A. A. S., 1872, p. 134.

[4] Recent Geological Discoveries among the White Mountains, N. H. Proc. A. A. A. S., 1872, p. 135. In this paper the author states his grounds for the correlation, viz., that of lithological similarity between the porphyritic gneiss and the Laurentian of Canada and Europe. At each of the next two meetings of the Association, he reaffirmed his position that there is nothing older in the state than the porphyritic gneiss which was held to be Archæan in age. See Geological History of Lake Winnipiseogee. Proc. A. A. A. S., 1873, B. p. 122, and the Physical History of New Hampshire, *ibid.*, 1874, B. p. 76.

[5] Proc. Bos. Soc. Nat. Hist., Vol. XV., p. 304.

tions of the lower series into two groups — the Laurentian, which he qualifies by an interrogation point, and the Labradorian. The former included the "porphyritic gneiss," Bethlehem gneiss, White Mountain, or andalusite-gneiss, and the breccia of Franconia, in the order of decreasing age. The eight members of the Labradorian "constitute one horizontal series of formations, the lowest resting upon the upturned edges of all the parts of group I." The greater antiquity of the "porphyritic gneiss" than that of the other series "is inferred from the occurrence of several bands of andalusite and granitic gneisses upon both flanks." It is interesting to note that in discussion on this paper Dr. C. T. Jackson declared his belief that "the classification proposed was hypothetical to a great extent, and that sufficient reason for the adoption of the New York nomenclature was not shown."

The first volume of the Final Report of the Hitchcock Survey was issued in 1874. The "porphyritic gneiss" was there explained as the product of altered sediment, the primitive stratified rocks having been metamorphosed in Archæan, or, as then expressed, Eozoic time.[1] The second volume, published three years later, reiterated this opinion, making the terrane the representative of the "first territory in the state that was redeemed from the primeval ocean."[2]

"A porphyritic, or augen-gneiss, is eminently characteristic of the fundamental rocks in every part of the world, and hence ours may readily be called Laurentian."[3] A still closer correlation was suggested whereby the "porphyritic gneiss" of the White Mountain district, and inferentially that of the whole state, was put in the "upper division of the Laurentian system, as it is developed in Canada and New York."[4] In the general résumé of the stratigraphical relations, a thickness of five thousand feet was estimated for the formation. With it was included the "younger Bethlehem and Lake Winnipiseogee gneisses to form the whole Laurentian, aggregating 34,900 feet in thickness.[5]

[1] Geol. of N. H., Vol. I., 1874, p. 512.
[2] Geol. of N. H., Vol. II, 1877, p. 519.
[3] *Ibid.*, p. 668.
[4] *Ibid.*, p. 252.
[5] *Ibid.*, p. 668.

From this brief review it is seen that the placing of the "porphyritic gneiss" so low in the geological scale was largely due to the prevalence of two pernicious doctrines then held in the study of crystalline schists. The application of the "lithological canon" was a constant feature in the efforts of the second survey to work out their difficult field. The coarse granitic gneisses, the augen-gneiss, and the andalusite-gneiss were each supposed to be represented in the typical Laurentian of the better known regions, thereby establishing synchrony. Again the distinct foliation in many parts of the "porphyritic gneiss" led to the other serious error of considering the rock as a metamorphosed sediment, which still preserved traces of its original planes of stratification.[1] This position being taken, it was but natural to look for structural relations with the surrounding formations, and at many contacts, the greater antiquity of the porphyritic rock would often appear evident. Needless to say, however, in the light of present knowledge, that all such reasoning is without foundation so far as it refers to large isolated areas of thoroughly crystalline schists. Thus the character of the terrane had to be determined by other methods. The latter were very sparingly used by the survey, and consequently its final conclusions assigned to the "porphyritic gneiss" the very important position of a foundation member in the entire geological series.

The interpretation of other terranes was, of course, greatly influenced by this fundamental idea. The survey fixed the geological position of the Bethlehem gneiss,[2] and of the Montalban group and the Lake Winnipiseogee gneiss[3] directly by reference to the "porphyritic gneiss," and the later succession was correspondingly affected. In fact, Professor T. Sterry Hunt's conception of and nomenclature of the Montalban group was founded on the conclusion that there is this demonstrable Laurentian in New Hampshire.[4]

[1] Geol. of N. H., Vol. II, p. 99.

[2] 1871. See Geol. of N. H., Vol. I, p. 34; Vol. II, p. 452.

[3] *Ibid.*, Vol. II, pp. 564,662.

[4] Geol. Mag., 1887, p. 1499; Nature, Sept., 1888, p. 521.

We have already referred to some hints of an igneous, intrusive origin for the "porphyritic gneiss," that were given by the survey officers. Similar suggestions appear in many parts of the different reports.[1] The facts described in these passages were supposed to be explained on the metamorphic theory as being characteristic of only those parts of the ancient stratified rocks which had been altered to the extent of complete fusion.

In his address as vice president of section *E* of the American Association in 1883, Professor Hitchcock expressed some modification of his earlier opinions on the origin of the porphyritic gneiss. He said: "A careful study of the crystalline rocks of the Atlantic slope indicates the presence of scattered, ovoidal areas of Laurentian gneisses. Those best known have been described in the geology of New Hampshire. Instead of a few synclinal troughs filled to great depths with sediments, the oldest group is disposed in no less than twenty-two areas of small size, scattered like the islands in an archipelago.[2] There are no minerals in these Laurentian islands that do not occur in eruptive granite; and the schistose structure is often so faint that the field geologist need not be blamed if he acknowledges his inability to detect it. Likewise we discover the same fluidal inclusions and the vacuoles that pertain to granite."[3] Comparing these islands to volcanic oceanic islands of the present day, he suggests that the foliation of the porphyritic gneiss may be the result of the superposition in quaquaversal sheets of lava about each volcanic cone, aided by flows of mud and wear by water between igneous flows. In this way we might have a "concentric statiform arrangement in the whole mass." Subsequent metamorphism by heat and pressure would lead to the development of new minerals in foliated beds.

The next important notice of this formation appears in Whitney and Wadsworth's "Azoic system."[4] They instituted a close

[1] See Geol. of N. H., I, pp. 27, 33; II, pp. 102, 472, 520.

[2] Proc. A. A. A. S, 1883, E., p. 186.

[3] Op. cit., p. 187.

[4] Bull Mus. Comp. Zoöl., Harvard College, Vol. VII, 1884, p. 383 ff.

criticism of the general methods of the New Hampshire survey, and looked with especial disfavor upon the liberal use of the "lithological canon," as accepted by the members of that survey. A convenient résumé of the various classifications proposed for New Hampshire rocks is given in tabular form at page 396 of the memoir. The possibility of an eruptive origin for the "porphyritic gneiss" was remarked by the authors.

In 1884 Professor Hitchcock stated that "all thoroughly crystalline series of the Atlantic region are of Eozoic age."[1] Two years later he edited the "Geological Map of the United States," in which the "porphyritic gneiss" is colored as Laurentian.[2] A somewhat full account of his opinions on the formation was given in a paper on the "Significance of Oval Granitoid Areas in the Lower Laurentian,"[3] from which it is evident that in 1890 Professor Hitchcock held practically the same views on the present subject as those which he published in 1883.

While the present paper was in process of preparation the last word on the formation was given by Professor Hitchcock in this JOURNAL. After tracing in a general way the history of geological surveying in New Hampshire, he makes the following significant statement of a changed point of view: "The question now arises, how can our early classification [of the rock series] be improved? It is eighteen years since the New Hampshire report was published, and there are many new workers in the field, all placing great reliance upon petrographical principles, such as were inaugurated in Dr. Hawes' report. Some are advocates of extreme metamorphism, and hence the conclusions are not harmonious. It seems to us that our early views may be modified by the following principles: (1) The mineral characters of crystalline rocks are not a sure guide to geological age. (2) Protogenes, diabases, and diorites, more or less interstratified with hydro-micas, are of true igneous origin. (3) The

[1] Trans. Am. Inst. Min. Eng. XII, 1884, p. 68. Cf. a paper in Proc. A. A. A. S. of the same year (p. 396) where he again holds the porphyritic gneiss to be Laurentian.

[2] Trans. Am. Inst. Min. Eng., Vol. XV, 1886, p. 465.

[3] Bull. Geol. Soc. Am., I, 1890, p. 557.

Archæan gneisses and protogenes may also be of igneous origin, and their apparent stratification has no connection with sedimentary or chemical deposition, etc. . . . . Applying such principles to the classification of the rocks of northern New England, we may improve on the report in several particulars. (1) Archæan rocks are not eliminated from our list. They exist as oval areas, such as have been indicated in the Stamford gneiss, and south of Mount Killington, Vt., in the Hinsdale, Mass., area, the Hoosac Mountain, and elsewhere. I recognize the porphyritic gneiss in the Stamford rock, and in the Hoosac tunnel as Archæan. (2) Our hesitancy about the place of the Bethlehem gneiss is met by recent observations. They are batholites, containing inclusions of the adjacent mica-schists. It does not follow that all these protogene areas are of the same character; each one must be studied by itself."[1]

However satisfactory such conclusions may be in their appli cation to most of the formations in the state, a clear statement of the true relations of the porphyritic gneiss has not yet been made. The author's recognition of the correct methods which must be used in interpreting crystalline schists has as yet not been supplemented very largely by their positive exercise in the field, and the implication in the foregoing extract that the Archæan appears in the state in "oval areas," either igneous or non-igneous, is still without demonstration.

We shall hereafter adhere to the name porphyritic granite, for the rock under discussion instead of porphyritic gneiss which has been so far used. As will appear later, the former name, while not embodying all the generalized features of the rock, is preferable to the official one of the second geological survey.

Geographical distribution.—The porphyritic granite, as shown on the survey maps, occupies four large areas with several smaller ones. Of these the largest one extends from Mount Monadnock, N. 5° E. to the northern flank of Cardigan Mountain, a distance of sixty miles; while it varies from three to

[1] The Geology of New Hampshire. JOUR. GEOL., Chicago, Vol. IV, 1896, p. 57.

twelve miles in width. Since this occurrence covers more than four times as many square miles as any other, it may well be called the "Main area." Associated with it in Sullivan, Merrimack, and Hillsboro counties, are some half dozen much smaller outcrops of the same rock which are surrounded by schists, and are thus outliers from the larger mass. Twelve miles west by south of Mount Monadnock, a second important mass of regular elliptical or oval-shape cuts cross the Ashuelot division of the Boston and Maine railroad. The longer axis runs north and south, and is about ten miles long, while the shorter, transverse to the former, is six miles long. From the village of Ashuelot, situated on porphyritic granite, we shall derive a distinctive name, and call this the "Ashuelot area." The survey has mapped a large "White Mountain area," which is distributed in irregular elongated form at the north of the Main area from Mount Stinson to Mount Lafayette. Some twenty miles long, it also varies considerably in width, being only a mile wide near the Profile House, but broadening out to six miles at the Kinsman Notch. From there a long tongue of the rock runs southerly down the valley of the Pemigewasset River. The strike of this area is like that of the Main area, a few degrees east of north. Following the common axis of both areas northward from the Profile House, a small but important "Littleton area" of some eight or ten square miles in extent, appears near the town of Littleton. The fourth widespread occurrence of the porphyritic granite is found in another irregular mass thirty miles long, and from one to eight broad, running parallel to the Main area from Laconia to Waterville. This may be referred to as the "Winnipiseogee area," from its proximity to the beautiful lake of that name.

The very local outcroppings of this rock in other parts of the state are in point of size insignificant, but they are of value in helping to determine the relations of the whole formation. Notable among these are the small patch on the top of Mount Prospect west of Squam Lake and the long dikelike mass north of New Boston in Hillsboro county. The grounds for coloring in the mass of porphyritic granite at the southeast base of Mount

Monadnock did not appear to be corroborated by the present writer in a somewhat careful study of that region. The mantle of glacial drift is there very heavy, but the few outcrops which were discovered seemed to prove the bedrock to be of the same nature as the schists round about. Again, a visit to Mount Osceola showed that the area of porphyritic granite plotted on the survey map as occurring on its southern side is really occupied by the same coarse-grained hornblende-granite which occurs in the bed of Mad River, the "Conway Granite" of the survey.

So great being the extent of the formation, it was impossible in the time at the disposal of the writer to make a close examination of all parts of the porphyritic granite. Accordingly, most of the observations in the following pages refer to three areas, the study of which promised to be most fruitful in the problem before us. Those selected were the Winnipiseogee area, the Ashuelot area, and the contact of the Main area from the town of Jaffrey to Henniker on the Peterboro and Hillsboro branch of the Boston and Maine Railroad. We shall consider these areas separately, treating of the geological results obtained in each along with certain other facts whose arrangement would be difficult by any other method of discussion.

Brief description of the porphyritic granite.— General macroscopical descriptions of the granite are given in several parts of the "Geology of New Hampshire." The rock is remarkably simple in its phasal differentiation; so far as a considerable collection shows, there are only two important variations in it throughout its whole extent. It may be either a porphyritic granitite or a porphyritic granite proper, and either of them may have the foliated structure. They pass into each other by insensible gradation in all the areas and it seems to be impossible to map them separately. With the exception of this and a few other variable features noticed in the sequel, the porphyritic granite is essentially uniform; it is thus possible to dismiss its characterization in a comparatively summary manner. In a future paper, the author hopes to give an account of certain

petrographical features whose description here is not rendered either advisable or necessary for our present purpose.

The name "porphyritic granite" for this rock is regarded as the best available one both on the ground of inherent meaning

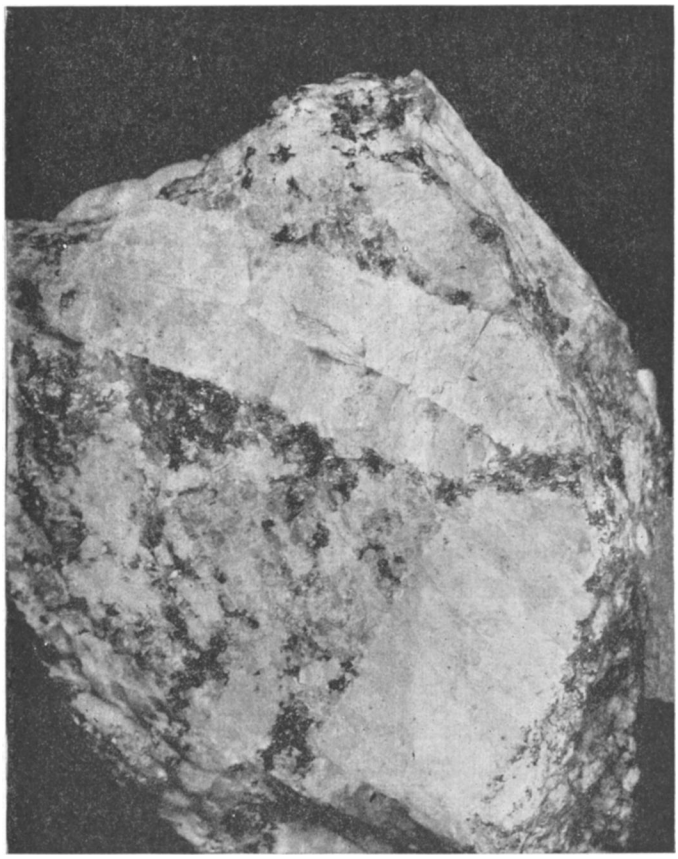

FIG. 1. — Photograph of a specimen of the porphyritic granite — obtained near New Hampton Centre — illustrating general habit of granitic phase, twinned phenocrysts, etc. — about natural size.

and of precedent. The composition and order of crystallization make it a true granite rather than a gneiss although the pseudo-schistose structure is so generally present. For very similar rocks, the names "granite-porphyry," "gneissic granite," etc.,

have been employed. It seems best to use the original name at first used by each of the New Hampshire surveys and in this we follow the nomenclature of Lehmann, Sederholm, Gümbel and others who have dealt with very similar rocks.

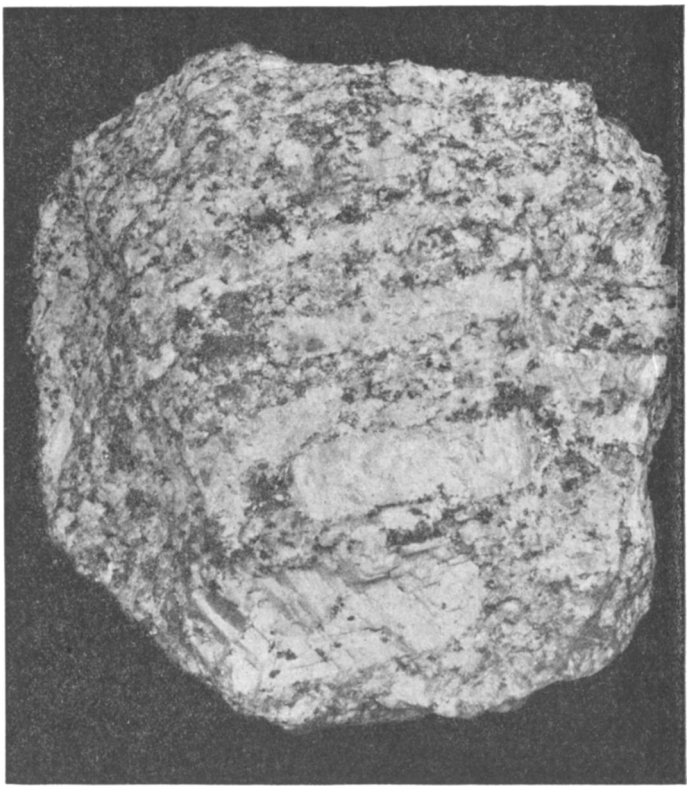

FIG. 2.— Photograph of a specimen of the porphyritic granite, showing a foliated phase near Hancock Station. The lowest phenocryst displays two prismatic partings besides the normal cleavages, parallel to *P* and *M*. The base is nearly in the plane of the paper. About one-half natural size.

The granite is always striking and handsome in appearance The groundmass is a coarse-grained, light to dark gray, granular aggregate of quartz and feldspar interspersed with flecks, blotches and lines of greenish muscovite and brilliant brown biotite.

Within are embedded the lustrous phenocrysts which generally, though not always, lie in the foliation plane when the rock has the plane-parallel structure.

The phenocrysts are glassy to opaque white and seem to be in every case either orthoclase or microcline, which may be intergrown with another (triclinic) feldspar in the usual microperthitic fashion. The largest ones are as much as twelve centimeters long. The usual habit is that of simple Carlsbad twins. They present straight edges to the surrounding matrix, giving the planes (001) (010) (110) and (101). This idiomorphic appearance is often lost in the slide through the great amount of resorption and marginal corrosion. Occasionally small shreds of biotite, a minute individual of apatite, or a few grains of quartz may appear in the core of the feldspar, but as a rule it is notably free from primary inclusions. The results of decomposition are normal. The changing to a reddish hue is common in some weathered phases.

The matrix of the rock is simply a typical coarse granitite on the one hand or a granite proper (in the classification of Rosenbusch) on the other, in either case with or without the foliated structure. The feldspars have the same general characters as those of the earlier generation except that a triclinic feldspar, probably andesine, now appears as an independent constituent. Quartz, biotite and muscovite constitute the other essentials. Large but relatively few individuals of magnetite, titanite, apatite and zircon are accessory. The quartz and feldspars are roughly equidimensional with diameters becoming as much as a centimeter in length; in fact the feldspars are often transitional into the phenocrysts. Quartz very often crystallized simultaneously with the feldspars resulting in the formation of a true micropegmatite which is extremely common in slides of the granite from all the areas. It is best shown in specimens collected along the railroad from Hinsdale to Ashuelot. There can be little doubt that the structure is primary in the formation as a whole. It is possible, however, that in zones of stress the development of the structure has been aided by the meta-

morphic cause of crushing, as described by Howitt, Hobbs and other writers.

The proportions of phenocrysts to matrix and of acid to basic constituents are quite constant in the porphyritic granite. The latter relation is that usually found in most highly acid granites. Now and then, a well-foliated segregational mass of biotite, quartz, much titanite and apatite, wrapping about phenocrystic cores of feldspar, may be encountered. Again, a phase of the rock nearly devoid of phenocrysts is not rare, although quantitatively it is insignificant as compared with the porphyritic phase. Both of these variations from the type will be discussed in what follows.

Field relations: The Winnipiseogee area.—The general distribution of the porphyritic granite in the Winnipiseogee area is described at length in "The Geology of New Hampshire."[1]

The topography of the area is, on the whole, not of a very definite nature. The greater reliefs, which vary from 800 to 1500 feet above sea level, are without distinct trends, and are the forms which might be expected as the result of eroding a massive rock of pronounced homogeneity. Upon this rolling ground the glacial drift has been deposited in unusual thickness, especially in the southern half of the area, where the hills are commonly composed of washed drift and till. Correlative with glacial reliefs are the glacial depressions seen in the numerous lakes and ponds which make such picturesque variety in the landscape of Carroll county. These modern deposits make it difficult to work out the relations of the bed-rocks. The variety of outcrops in many parts renders the determination of contact lines almost impossible, and it is largely to this cause that the suppositional nature of some of them is due.

The geological relations of the Winnipiseogee area.—The survey map places the porphyritic granite of this area in contact with the Lake Winnipiseogee gneiss, the Montalban group of schists, the Rockingham mica-schist, and the various eruptive masses of Waterville. For convenience we shall briefly indicate

[1] Vol. II, p. 592.

the facts of field observation which have been adduced in connection with each of these formations.

The porphyritic granite in contact with the Lake Winnipiseogee gneiss.—Close by Gilford Station, on Smith's Neck, the boundary line of the porphyritic granite and the Winnipiseogee gneiss appears, and, so far as known, this is its most southerly extension in this district. It is a typical acid biotite-gneiss at this place, elsewhere muscovite may be found. A few of the outcrops are significant. Here and there in the porphyritic granite masses of rock very similar to the main body of the schist occur in a horselike relation, although nowhere could the actual contact be found, and thus render possible a proof of that derivation of the masses. On Governor's Island, two miles to the westward, a large outcropping of a coarse muscovite-biotite-gneiss occurs. This is a typical representative of the Lake Winnipiseogee gneiss, and this mass is completely surrounded by porphyritic granite for a distance of at least a quarter of a mile in all directions. About that distance from this outcrop of schist, the real contact of the porphyritic granite and Lake Winnipiseogee gneiss was found, and it became evident that in the first occurrence we had to deal with an outlier removed by some means from the parent schist terrane. This relation could hardly be explained except on a hypothesis of the igneous intrusion of the coarser rock in which the schist was enclosed as a great horse. The truth of this supposition was strengthened by the discovery of two marked apophyses of the porphyritic granite running into the inclusion. Returning to the molar contact, a corroboration of our conclusion from a study of the outlier appears in a clearly defined tongue of the porphyritic granite which can be traced for some distance into the schist. Whereas on Smith's Neck the porphyritic granite was largely granitic, here a well-defined foliation characterizes the rock. The strike of the foliation planes is N. 3° E., and the dip is 82° to the east. It is noteworthy that the strike and dip of the schistosity in the adjacent schist is the same. In other words, there is an apparent conformity between them. At several places among the numerous outcrops of porphyritic gran-

ite on the island, very coarse pegmatitic dikes appear which are similar to the granite, and do not appear to belong to the class of pegmatite veins of segregational origin so common in the crystalline area of the state.

About a mile and three-quarters from Weirs there is a small inlet, on the south side of which the porphyritic granite is in contact with a dark coarse-grained gneiss. This seems to be equivalent to the Lake Winnipiseogee gneiss. It is cut by an apophysis of the porphyritic granite, and a horse of the schist can be seen on the bare ledges enclosed within the other rock. Again, as on Governor's Island, there is an apparent conformity of position.

Just across Meredith Bay, on Spindle point, an interesting contact occurs. The porphyritic granite outcrops occasionally on and about the road from Meredith with pretty definite foliation, the strike varying from N. 20° E. to N. 40° E., the dip high, but changing from easterly to westerly in an irregular fashion. On the top of the hill at which the road ends, an solated mass of another rock is conspicuously displayed in the well-smoothed ledges. It is dikelike in its form, being fully four hundred yards long and from ten to twenty wide. There is a distinct schistosity with its planes parallel to the longer axis of the mass which strikes S. 40° W. The dip is high at about 75° to the southeast, making an apparent conformity with the enclosing porphyritic granite, which is here well foliated. Within a distance of 300 yards south of this long band, and oriented with the longer axis parallel to it, smaller bodies of the same rock occur, again completely enclosed by porphyritic granite. They have the same pronounced structure-planes with a similar relation to the foliation of the country rock. From the hill top the largest of all these parallel bodies strikes toward a larger body of the same rock. Like the other, this mass is characterized by a strong gneissic structure. It also possesses an elongated form. We have here to deal with a number of horses immersed in a once molten magma which chrystallized out as porphyritic granite. The patent differences of grain and

structure, the sharp boundary between the two rocks, the irregular thinning and thickening along the length of the inclusions, all point to this belief. Here and there, within their boundaries, obscure apophysal extensions of the coarser rock may be observed. But this conclusion reaches practical certainty when the molar contact of the porphyritic granite and the "Lake Winnipiseogee gneiss" is studied. The latter is seen to be precisely the same coarse-grained biotite-gneiss as that in the inclusions, except for certain differences which can be explained as due to exomorphic change wrought by the porphyritic granite. Apophyses of the latter may be seen at the neck or isthmus of the peninsula cutting the gneiss. An important relation subsists between this line and the arrangement of horses on the hill. Not only are they parallel to one another, but they lie parallel to the line of molar contact.

Transition zone at Centre Harbor.—At Centre Harbor the gneiss lies on the east side of the boundary and at some distance from it is the usual coarse-grained muscovite-biotite rock of the Lake Winnipiseogee gneiss terrane. Its foliation planes strike N. 15° W., and the dip is about 60° easterly. As one approaches undoubted porphyritic granite through a distance of fifteen feet from the contact, one notes the large orthoclase and microcline feldspars two inches long, which normally are confined to the porphyritic granite, now scattered through the finer-grained rock with their longer axis parallel to its schistosity. They grow more numerous as the porphyritic granite is neared, until finally some four or five yards from their first appearance, the outcropping rock is typical porphyritic granite. It possesses the same strike and dip as the gneiss, being well foliated. There is thus a complete and slow graduation of the one terrane into the other, making it impossible to draw any line between them.

Transition zone near New Hampton Station.—A similar zone of transition between these two terranes occurs a mile and a quarter from New Hampton Station on the road running southeast from the station. The zone of passage is here much wider

than at Centre Harbor, but the properties of its magmalike gneiss with the sprinkling of large porphyritic crystals of feldspar are identical with those of the other locality. As a rule, there is a sharp contact between the porphyritic granite and the invaded rocks, like that which in general characterizes plutonic bodies. These belts of transition have at first sight a puzzling appearance. That they are, in reality, eruptive contacts seems, however, to be unquestionable. Durocher long ago noted such an intimate union along the boundary of gneiss cut by stock-granite. He considered the temperature of the igneous rock in such instances sufficiently high to produce a melting up of the gneiss the "particules" of which "ont dû posséder une assez grande mobilité, et cristalliser à peu près dans les mêmes conditions que les molécules du magma granitiques.[1] In his "Geog. Beschreibung Bayerns,"[2] Gümbel speaks of there being numerous transitions from "bunter gneiss" to "bunter granit" which cuts the former. Michel-Lévy has very clearly discussed the phenomenon in general. He says:[3] "C'est ici le cas de remarquer que lorsque deux grandes masses de roches acides se touchent, le plus souvent elles se trouvent réunies par une zone de passage plus ou moins puissante, dans laquelle les caractéres pétrographiques des deux roches sont, pour ainsi dire, confondus et mélangés.[4] In the same paper from which this quotation has been taken, the author cites many examples of such transition, among which that from granite to gneiss[5] and that from granite to "micro-granulite" may be especially mentioned. He explains them as due to an impregnation of the older rock by "les éléments fluides en voie de dégagement" from the igneous rock. When the temperature and pressure are suitable, a part

[1] Mém, de la Soc. Géol. de France, 2e sér. t. VI, p. 47.

[2] Abtheil. II, p. 272.

[3] Bull. de la Soc. Géol. de France, 3e sér., t. VII, 1878–9, p. 852.

[4] Cf. Ch. Vélain, Conférences de Petrographie. Paris, 1889, p. 6.

[5] Cf. LEHMANN, Untersuch. über die Ent. der alt. kryst. Schiefergesteine, p. 76. GREGORY, Q. J. Geol. Soc., 1894, p. 260 ff. BARROW has noted a complete amalgamation at the contact of granitite and diorite, of which the former is the intrusive member, Q. J. Geol. Soc., 1892, p. 121.

of the constituents of the older rock will become mobile and will tend to assume the same structure as those of the second period of consolidation in the younger rock.

McMahon pointed out how difficult it was to explain the presence of zones of transition about the Dalhousie granite of the Himalayas in some places and their absence in others on the old metamorphic theory of the central gneiss. He favored the opinion that, whether a zone of passage characterizes the contact or not, depends on the closeness of mineralogical similarity between the Dalhousie granite and the invaded strata. Only in places where the latter had been regionally metamorphosed did he find the appearance of gradual change from the granite into the country rock. The transition zone described by Lawson between the Laurentian gneiss and hornblende-schist in Rainy Lake region is so similar to the zones of the porphyritic granite that it will be well to read his own words on the subject: "Within the hornblende-schist, distinctly recognizable as such, there may occasionally be detected large crystals of red feldspar, which is quite foreign to these rocks, as if the feldspathic magmas had penetrated within the schist and crystallized there in the same large crystals in which they are wont to appear in the coarse gneiss."[1]

These authentic determinations of transgressive junctions between plainly eruptive rocks and their respective country rocks, coupled with the expectation that they should appear in contacts of that nature, lead us to follow Gregory [2] in concluding that they may form a useful criterion for a decision on an eruptive origin for massive rocks. So far as this principle is concerned then, the porphyritic granite can be eruptive.

The foregoing description of contact phenomena seems to us to indicate that the porphyritic granite has been intruded into the schistose rocks which have been grouped together in the terrane of the Lake Winnipiseogee gneiss by the survey. This conclusion is forced upon one as well in the study of the northern

[1] Ann. Rep. Geol. Surv. Canada, 1887–8, Part. F. p. 33.

[2] Q. J. Geol. Soc., 1894, p. 262.

extension of the "fishhook" as in the southern part to which attention has been so far called.

The porphyritic granite in contact with the Montalban group of schists.—We shall not consider in this place the grounds on which the survey has separated the Lake Winnipiseogee gneiss from the Montalban group. Our field observations have shown us pretty clearly that, although the lithological characters of the two terranes may be on the whole different, any distinction between them from a supposed difference of age is as yet without demonstration. Be this as it may, the problem before us can be solved without either proof or disproof of such a contention. At many points along the contact, the schists of the Montalban group are intersected by apophyses from the porphyritic granite, and appear as inclusions in the latter rock. The evidences of an intrusive origin for the porphyritic granite are of the same nature as in the case of the Lake Winnipiseogee gneiss, and are just as conclusive.

The Montalban group and porphyritic granite come in contact along the line running from Long Bay to Great Bay, and about one half mile east of Great Bay. Here a number of well-marked horses of the neighboring Montalban gneisses occur in the porphyritic granite. They possess a thoroughly gneissic structure, being as well foliated as their parent mass less than a hundred yards away. In this case the horses are not elongated and do not show any definite relation of position, either to one another or to the main contact line. Apophyses of porphyritic granite were also discovered along this part of the boundary.

An interesting occurrence of the gneiss appears in the road on the north side of Shaw's hill. It is isolated and completely surrounded by porphyritic granite whose nearest molar contact is nearly a mile away. This great horse is highly schistose, and several tongues of the granite here and there cut across the structure planes. The development of garnets in the horse may hint at some degree of contact metamorphism.

A second large horse which is some distance from its parent

terrane outcrops one mile and a half north of Holderness on the upper road. Here a gigantic slice of the country rock, about sixty feet wide and three hundred feet long, has been floated off and rests with its longer axis north and south, *i. e.*, parallel to the molar contact. It is composed of the usual biotite gneiss in which a thick sheet of hornblende-gneiss lies embedded, making up most of its mass. The latter has itself the appearance of being an eruptive rock which is thus older than the porphyritic granite. Associated with it are a large number of smaller biotite gneiss fragments which have no definite arrangement, but make a confused medley of discreet masses in the porphyritic rock. The whole looks like a huge flow breccia. Rather more than a half mile further north on the same road, there is a breccialike aggregation very similar to the last, even to its containing hornblende-gneiss folded up in a large mass of biotite-gneiss.

Three hundred yards west of where Dr. Dana's road leaves the four corners at New Hampton Centre we note another of those zones of transition between the porphyritic granite and the schists in contact with it. It is some twenty feet wide, and is strikingly similar in appearance to the case already described at Centre Harbor. Here the schist is cut by intrusive tongues with more or less sharp boundaries. These apophyses run across the gneissic planes.

On the extreme eastern end of the Sandwich Mountains at an elevation of about seven hundred feet above the Bear Camp River, a remarkable flow breccia or "permeation area"[1] outcrops in some extensive pasture fields. The rock presents all the features of a plutonic flow. The horses are here almost entirely hornblende-gneiss, some of them massive, both fine-grained and coarse-grained, others distinctly schistose. The porphyritic granite is on the whole granitic in appearance, but at the boundaries of the fragments, the feldspar phenocrysts are often oriented about them in a way which is strongly suggestive of a flow structure. The usual trendless nature of its constitu-

[1] Barrow, Q. J. Geol. Soc., 1893, p. 331.

ents is also lost in some of the tongues of porphyritic granite which penetrate the fragments in all directions. There the minerals are pulled out in planes parallel to the walls of the intrusion. The source of the hornblendic inclusions was discovered within a hundred yards of the breccia. An unknown thickness of the hornblende-gneiss lies interbedded in the biotite-gneiss. This great breccia outcrops at several places through a distance of three hundred yards along the base of the mountain and is only one hundred yards from the massive terrane of the Montalban group, which is continuous all the way from Morgan Mountain.

These occurrences of hornblende-gneiss in the porphyritic granite throw light upon the "hornblende rock" which was noted by Hitchcock in the Survey Report[1] as occurring to the east of Wickwas Pond. It covers altogether about an acre in extent. The rock is a hornblende-gneiss closely related in composition to the masses already described. It has a strong schistosity which lies parallel to the foliation of the granite enclosing it. The latter sends intrusive tongues into the gneiss which is evidently a large floe of the country rock moved far from its original source.

The small oval area of the porphyritic granite on the top of Mount Prospect is a stocklike body which suggests from its position an intrusive origin. Field study confirms this opinion. The rock is typical of the porphyritic granite in composition, in grain, and in the size of the phenocrysts. Within this porphyritic granite there are embedded several horses of the surrounding Montalban schists. The latter are extensively crumpled, perhaps by the intensity of the granitic intrusion. Again one can notice the parallelism of the phenocrysts to the margins.

The porphyritic granite in contact with the Rockingham mica-schist.—One of the most important localities in the state to suggest an intrusive origin for the porphyritic granite is on Saddle Hill, where that rock comes in contact with the Rockingham mica-schist. Here the formation is composed of well-

[1] Vol. II, p. 594.

foliated, fine-grained, muscovite-biotite-schist with abundant mica. The molar contact is found on the eastern end of the hill. It strikes N. 25° W., and is parallel to the schistosity of the mica-schist and to the pronounced foliation of the porphyritic granite. All the structure planes dip westward at a high angle. Going across the strike from the contact toward the porphyritic granite a remarkable series of elongated horses of the schist interrupt the continuity of the granite. They are usually much longer than their width, as, for example, a large one 150 feet long by 35 feet wide, which appears on the west side of the saddle. In most cases there is a definite orientation of the horses parallel to the contact line, while the foliation of the porphyritic granite wraps around the inclusion in a significant way. They are uniformly schistose with that structure as well developed as in the main body. Crumpling of the horses is also characteristic. For about two hundred yards east of the contact, the schist is cut by several intercalated sheets of porphyritic granite, varying from five to ten yards in thickness. Their phenocrystic feldspars lie parallel to the walls between which the sills were intruded. Similar sheets can be found in the pasture on the southern flank of the hill and west of Randlett Pond.

Relation of the porphyritic granite to the Waterville eruptives.— It is probable that the porphyritic granite is older than all of the intrusive rocks of the Waterville Mountains. The contacts were discovered in only one place, namely, on the southern slope of Mount Whiteface; there the hornblende-granite composing the mountain distinctly cuts the porphyritic granite. In the path from the Elliott House, at Waterville, to the top of the Sandwich Dome, many outcrops of several types of granitic rocks present a problem of correlation which the writer has had no opportunity to solve. It is possible that these rocks are chilled phases of the Conway granite; for there is, in the main, a tendency towards a porphyritic structure throughout, which on the one hand becomes more pronounced as one approaches the porphyritic granite, and is entirely lost in the very coarse Conway

(hornblende) granite in the bed of the Mad River. If this hypothesis be correct, the Conway granite is younger than the porphyritic granite, for at about 1800 feet above the river the porphyritic phase distinctly cuts the coarser rock.

The Ashuelot area.—The country rock about the porphyritic granite of the Ashuelot area is referred by the survey to three different formations. the Bethlehem gneiss, the schists of the Coös group and the Montalban group. Specific reference to this area was made in the second volume of the Survey Report.[3] In

[3] P. 470.

their general correlation, the survey considered the markedly oval form of this and other occurrences of the porphyritic granite as allying it in point of age to similarly shaped masses in the Archæan elsewhere. Such a form has a nearer homologue to the batholites described by Emerson in western Massachusetts, and as we shall see, these similar forms have similar origins. That the porphyritic granite of the Ashuelot area is eruptive and of an intrusive nature can be amply proved. We shall not attempt to trace the evidence from the contact-phenomena, as it might be traced in a complete description of the whole boundary. It is of the same nature as that outlined for the Winnipiseogee area. With that fact in mind, we have considered it expedient to refer to a few only of the possible localities which can be readily visited for confirmation of our views.

A representative contact of the porphyritic granite and Coös mica-schist outcrops where the boundary line between them crosses the road running southwest from Ashuelot over Gun Mountain. Here and along the western ridge of Gun Mountain the typical biotite-muscovite-schist is strongly charged with interbedded actinolite-schist and quartzite. Several apophyses of the porphyritic granite cut the schist. One of them, twenty feet wide, cuts across the strike, extending a considerable distance from the contact before it disappears under the soil-cap; another over two feet in width is also well exposed, but lies nearly in the planes of schistosity. Horses of schist are embed-

ded in the granite, but the overlying loose deposits prevent the discovery of any definite arrangement among them. The granite itself has a good parallel structure, and it is important to note that its structure-planes are conformable in strike and dip with those of the adjacent schists. This same conformity was several times observed along this western side of the area. Sometimes, even at the contact, the porphyritic granite is quite granitic without a trace of the foliated structure. A good example of this appears at the contact on Hall's hill, near Chesterfield factory. At this locality, too, there is no doubt as to the relation of the two formations. The intrusive tongues of porphyritic granite cut across the schists and associated gneissic bands in a very marked way; the sharp contrast of grain and composition enabling one easily to differentiate the igneous masses. Occasionally dikes of the porphyritic granite may be found traversing the schists at a distance from the contact. At the three corners, about a mile south of Chesterfield, numerous great veins of coarse pegmatite outcrop and with them occurs a set of true porphyritic granite dikes which are probably apophyses of the main mass, half a mile away.

Facts of like character refer to the contact with the Bethlehem gneiss on the eastern side of the oval. Field evidence shows that the latter is of the same metamorphic epoch to which the Coös mica-schist is referred; thus, the argument regarding the better exposed part of the boundary applies to it in its entirety.

Fitzwilliam area.—We have seen already that the survey suspected an eruptive origin for certain parts of the porphyritic granite, and had cited facts from the Fitzwilliam area as in part the basis for the conception. The contact line of this little patch of the rock is very clear in its teaching. Even more graphic than that of the bowlders described in the survey report[1] is the evidence where the rock is in place. About a mile southwest of the village the porphyritic granite is found in a pasture field by the roadside. Included in it are many horses of biotite-

[1] Vol. II, p. 471.

gneiss, some of which are large, being as much as twenty-five feet in diameter. Within one of the latter an interesting irregular injection of the porphyritic granite is well exposed. One feature exceptionally well shown is the fine-graining along the margins. At this place, too, dikes of the Concord granite cut the porphyritic granite, and the former rock is thus the youngest terrane in the region. Since it surrounds the porphyritic granite on all sides, this Fitzwilliam occurrence may itself be a large floe brought up from below from a much larger mass.

The Main area.—Our observations on the Main area were extended only to its southern half. The great thickness of the various glacial deposits make it, on the whole, less satisfactory for a study of contact relations than the Winnipiseogee area. We have aimed in the course of a somewhat hasty examination to discuss the facts as regards the schists grouped by the survey under the names of the "Ferruginous slates," and the "Ferruginous schists." In both, the rocks consist of two-mica-schists, biotite-schist, biotite-gneiss, and muscovite-biotite-gneiss, all of which may be garnetiferous. Between them we can trace no definite distinction, either of composition or of age, and the area on the eastern border, marked "Lake Winnipiseogee gneiss," encloses stripes of schistose rocks which are identical with those of the above-mentioned groups. Here, as often elsewhere, the grounds for the subdivision carried out by the survey do not appear in the field.

The great sill of porphyritic granite to the north and northeast of Greenfield has one contact well exposed with interruptions for the distance of a mile. It is an intrusive one. The granite was erupted into the schists along a plane of foliation, and there is the usual development of parallel structure in many of its outcrops which accords with that of the walls. The intrusion is, on the whole, sheet-like in its form, though in some places where the schists are intensely folded, it cuts across their structure-planes. In such cases the foliation of the porphyritic granite remains parallel to the boundary line. The apophyses penetrate the schists irregularly in all directions, generally pay-

ing no attention to planes of weakness. They are finer-grained than their parent sill, but show here and there a feldspar as much as two inches in length.

One of the most interesting parts of the contacts is that which belongs to the area marked "Lake Winnipiseogee gneiss" by the survey in the towns of Antrim and Hillsboro. It is exceptionally well exposed at intervals for a distance of five miles, and especially on the long ridge some two miles west of Antrim. The name thus given the rock with which the porphyritic granite here comes in contact is a decided misnomer. The new terrane consists of an ancient metamorphosed eruptive cutting the "Ferruginous" rocks in every way similar to the schists that extend from Bennington to Henniker. This complex is itself cut by the porphyritic granite.

The older eruptive rock is a typical coarse granitite containing a good deal of muscovite which is all secondary. The quartz is the common blue variety of New Hampshire crystallines. Both orthoclase and a basic plagioclase occur, but they are generally badly decomposed. It is a difficult rock to diagnose thoroughly on account of the vast amount of crushing which appears in the thin section. The quartz and feldspars are much granulated marginally, the unbroken cores showing the characteristic wavy extinction. The plagioclase lamellæ are often bent through large angles. Minute faulting is common in them, and throughout the slides the shreds of biotite are bent and twisted in a striking manner, while the extinction on the base of biotite plates is most irregular. In fact the condition of this rock is in marked contrast with that of the porphyritic granite close by. The granite is quite without any signs of serious disturbance; the granitite has endured the very severe mechanical strain of extensive mountain-building. Often the signs of developed schistosity in this once massive rock are easy to discern in the ledges, and these new structure planes strike a few degrees east of north, *i. e.*, they lie in the main parallel to the strike of the "Ferruginous" terrane.

Now, within the crushed granitite there is an extraordinary

display of inclusions, varying in size from small fragments to masses twenty feet square, all of which have evidently been derived from the older schists to which they are mineralogically and structurally similar. These horses are highly ferruginous, and weather with the same rusty appearance that characterizes the parent rock. So great is their number in some places that considerable stretches are veritable flow breccias. But it is rather the remarkable crumpling and other evidences of intense folding which attract one's attention to these outcrops. The sliverlike horses are very often bent into sigmoid flexures; sometimes one is seen to be completely doubled back on itself in a nearly closed fold. They are usually much jointed, and here and there actual movement along a fault plane may throw one part of the inclusion a foot or more out of its normal continuity. While there is not much difference mineralogically between these inclusions and the rock of the ferruginous terrane, yet there is some evidence of a metamorphic change due to the granitite. About one of them, some two feet long and a foot and a half broad, in particular, a two-inch zone filled with large biotites was developed. The biotite of the granitite itself is often segregated in large individuals. Many of the horses have been considerably melted up, and it is probably the absorption in this way of so much of the iron oxides that conditions the characteristic deep reddish brown color of the weathered granitite.

This terrane has but few affinities with the simple Lake Winnipiseogee mica-gneisses, where they occur in their normal fresh uncrushed habit. No evidence is yet forthcoming that the latter are eruptive. Not only do these multitudinous horses prove the eruptive origin for the granitite, but its actual contact with the ferruginous schists was found on Riley Mountain, and it tells the same story. The usual field criteria of the presence of horses, apophyses, and intrusive sheets are there exhibited. A rock zone of the foregoing description, averaging rather more than a quarter of a mile in width, runs southward five miles to the Antrim ridge above mentioned, always appearing between the porphyritic granite and the main body of schists.

At many places along its western margin the porphyritic granite cuts the granitite, but often passing into it by a zone of transition analogous to those described in the Winnipiseogee area. Thus we have added another to the crystalline terranes which have been profoundly affected by dynamic processes since their formation; they are in this respect to be contrasted with the younger relatively unaltered porphyritic granite, and lastly, they are of interest not only from their relation to the history of igneous activity in the state, but also from the light that they throw on the age and origin of the granite.

REGINALD ALDWORTH DALY.

(To be continued.)